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PERFORMANCE REQUIREMENTS FOR AIRBORNE INFRARED FOREST FIRE SURVEILLANCE EQUIPMENT

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ABSTRACT

Performance requirements for a real-time recording, bispectral, line-scanning infrared equipment are outlined for application to forest fire detection and mapping.

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KEYWORDS: Aerial fire detection; Aerial mapping; Remote sensing; Fire surveillance; Infrared scanning.

This document delineates requirements for airborne infrared (IR) forest fire surveillance equipment (FFSE) capable of detecting and indicating the locations of small latent-stage forest fires and accurately mapping terrain details to establish the perimeters of large forest fires.

An airborne IR forest fire surveillance system must:

1. Detect a small, latent-stage forest fire in the presence of background temperature extremes;[2]

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[2] Ralph A. Wilson, S. N. Hirsch, B. J. Losensky, and F. H. Madden. Airborne infrared forest fire detection system: final report, p. 17. USDA For. Serv. Res. Pap. INT-93, 99 p., 1971.

2. Present information in such a way that a photointerpreter can accurately locate the fire;

3. Patrol large areas;[3]

4. Locate small spot fires adjacent to a large fire;[4]

5. Image large fires in such a way that fire perimeters, including smoldering edges and flaming fronts, can be accurately established;[5]

6. Locate small, hot fires within a large burned area during mop-up operations;[6]

7. Make near real-time, quality imagery of the area traversed for navigation; for in-flight interpretation of fire location; and for fire camp interpretation of a large fire's progress and of dangerous areas (e.g., unburned areas within the fire, spot fires, major fuel changes, and the fire's relationship to high-value areas).[7]

The above criteria indicate a need for fire-detection equipment that quickly detects and locates small, latent-stage fires while surveying large forested areas, and for fire-mapping equipment that provides good background detail (e.g., roads, firelines, and fuel breaks to the nearest 50 feet[8] outside the fire perimeter.)

Fire detection requires a fast aircraft at high altitudes; fire mapping usually calls for a slower plane at lower altitudes. The type of aircraft and its operation determine which mission is to be performed. However, similar requirements for locating small, lightning-caused fires and small hot spots near the perimeter of a large fire help define standardized fire detection/fire mapping equipment.

While covering a search area at a rate of at least 2,000 square miles per hour from 15,000 feet above terrain with backgrounds ranging from 0° to 50° C., operational equipment must detect (with nearly 100 percent probability) every unobscured, 1-square-foot, 600° C. fire.[9] Of equal importance, image quality must be sufficient to permit interpretation of fire location to the nearest 40 acres.

While covering a large fire at a rate as low as 150 square miles per hour, operational equipment must image large fires without distortion on the imagery adjacent to hot areas so that the fire perimeter, including smoldering edges and flaming fronts, can be located to the nearest 50 feet.

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[3] Ibid.

[4] Stanley, N. Hirsch, Robert L. Bjornsen, Forrest H. Madden, and Ralph A. Wilson. Project Fire Scan fire mapping final report, April 1962 to December 1966, p. 33. USDA For. Serv. Res. Pap. INT-49, 49 p., illus., 1968.

[5] Ibid.

[6] Ibid.

[7] Stanley N. Nirsch. The scope of remote sensing applications to forest fire control. *In* Workbook for Remote Sensing for Forest Fire Control Seminars, Spring 1971. Copies on file at Northern Forest Fire Laboratory, Drawer G, Missoula, Montana 59801.

[8] A compromise by the author from private conversations with Fire Scan personnel and Division of Fire Control personnel whose estimates range from 20 to 100 feet.

[9] An emissivity approximately equal to 1 is assumed.

From these requirements, a figure of merit (N) can be established for an IR FFSE:

$$N = \frac{\sqrt{\text{area scanned/unit time}}}{\text{temperature sensitivity} \cdot (\text{angular resolution})^2}$$

$$= \frac{\sqrt{\frac{\text{TFOV}}{(\text{IFOV})^2} \cdot \frac{V}{H}}}{(\Delta T)\ (\text{IFOV})} \geq 0.322$$

where:

TFOV = total field of view in radians
V/H = velocity-to-height ratio of equipment in radians/second
IFOV = angular resolution in milliradians (mrd)
ΔT = temperature sensitivity in °C.

DEFINITIONS

Small forest fire	For this specification, at least 1 square foot of hot burning material (600° C.) that does not meet the requirements of a large forest fire.
Large forest fire	Any fire that has escaped initial suppression forces and requires additional manpower to contain.
Spot fire	Similar to the small forest fire, but near a large forest fire.
Background	All objects within a surveillance area that have radiometric temperatures of 50° C. or less. Other signals normally considered as background (e.g., solar reflections from buildings or water, geysers, and hot highways) are excluded and must be taken into account when targets are interpreted.
Gray scale	Defined as $1/\sqrt{2}$ times density from the maximum density to fog level of the image medium.

IR FFSE PERFORMANCE REQUIREMENTS

A near real-time, line-scanned, contiguous and continuous in-flight thermal processed image of the terrain traversed must be produced and all fire targets superimposed on the thermal background image.[10] Figure 1 is a block diagram of an existing system doing this job.

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[10] Stanley N. Hirsch. Application of infrared scanners to forest fire detection. Int. Workshop Earth Resourc. Surv. Syst. Proc., Vol. 2:153-169, illus., 1971.

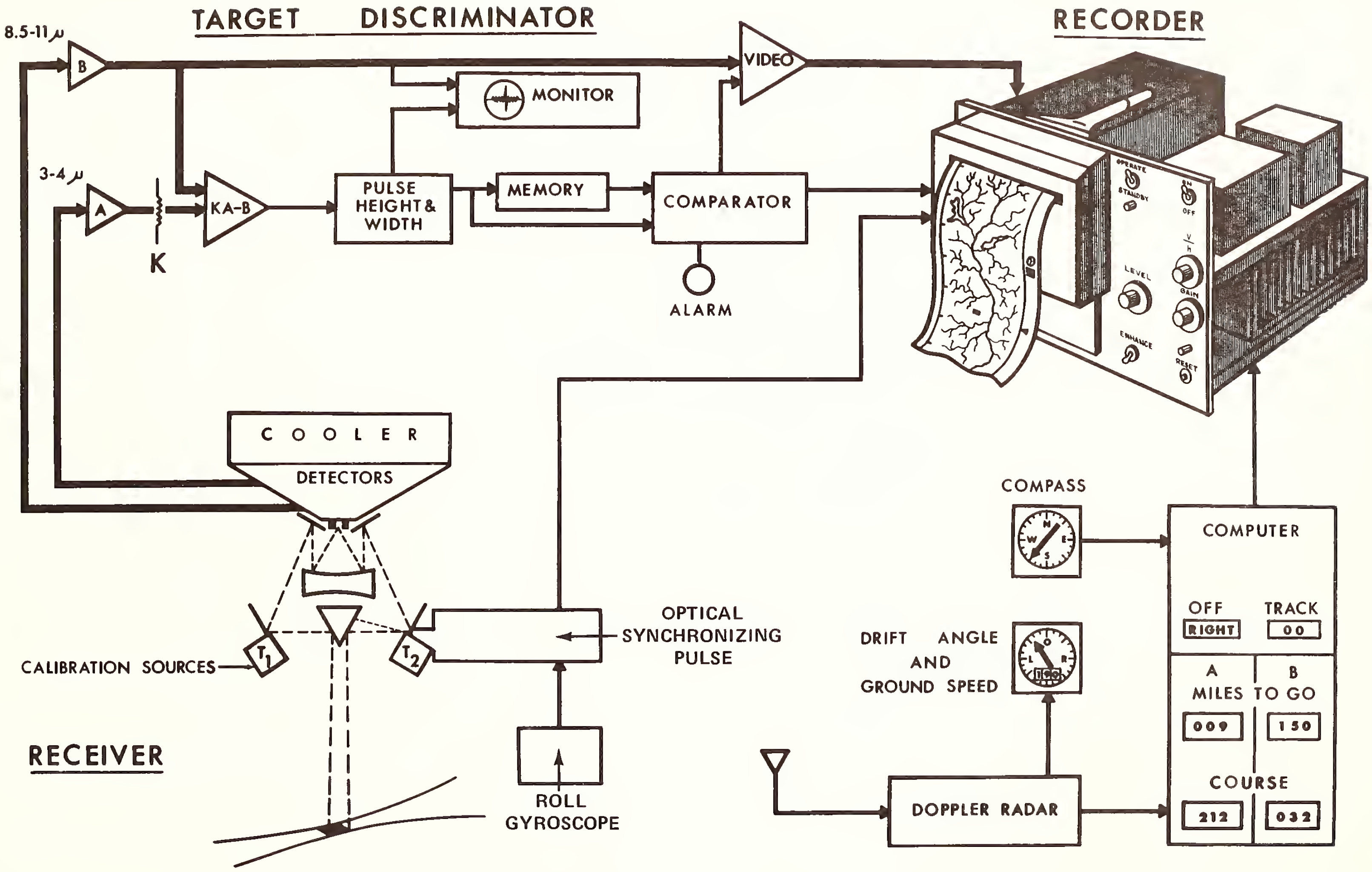

Figure 1.--Infrared fire surveillance prototype equipment block diagram.

Equipment Modulation Transfer Function (MTF)

The transfer function for the FFSE is defined as a function that relates image density in gray scales and a range of background temperatures in degrees centigrade (°C.) to the angular resolution or sampling rate. Three points on the MTF curve near the high resolution (fast sampling) limit of the system are defined as minimum: 85 percent modulation at 4 mrd IFOV; 50 percent modulation at 2 mrd IFOV; and 10 percent modulation at 1 mrd IFOV. The low resolution end of the MTF curve is direct coupled to insure a stability that results in less than 1-gray scale drift on the image for every hour of operation.

Target Discrimination

The success of an FFSE depends entirely upon its ability to locate and mark small fire targets on the imagery. The FFSE must discriminate and mark small fire targets with a radiometric power of 1/10, the maximum background variation, on the imagery and at the same time reduce false alarms to near zero. Discrimination of small targets is based on spectral discrimination at two radiometric wavelengths (see fig. 1): spectral band A has a wavelength near the peak power of a 1,000° K. fire; spectral band B has a wavelength near the peak of the background power (300° K.).

In addition to spectral discrimination, scan-to-scan and time correlation is used to eliminate spurious aircraft noise, navigation pulses, and external radar signals that have time durations less than four times the IFOV.

Temperature Sensitivity

Bispectral (two independent spectral channels) equipment images one channel with background temperature sensitivities of 1/2° C. or less when adjacent to 1,000° K. sources and maintains a good signal-to-noise ratio in the nonimaged channel. For optimum performance, the two channels must be matched to changes in atmospheric moisture from 1/2 to 2 cm. of precipitable water in the path length.

Total Field of View (TFOV)

A 120° active scan (±60° nadir) along with ±10° roll correction, a total unvignetted scan of 140°, is required.

Radiometric Calibration Sources

Two thermal calibration sources are used. Each fills the total scan aperture at different times during the scanner dead time; so the two extremes of normal background temperatures experienced in a forested background are covered. Temperature ranges recommended are from 0° to 20° C. (T_1) for one source and 35° to 55° C. (T_2) for the second, figure 1.

Velocity-to-Height Ratio (V/H)

A scanner V/H of at least 0.2 radian/second gives the 2:1 overscan required for target discrimination with a maximum aircraft V/H of 100 knots/1,000 feet. Higher scanner V/H's permitting more overscan are permissible.

Roll Stabilization

Roll stabilization must meet the requirements in each applicable aircraft. Roll stabilization over a ±10° range is required over the TFOV.

Slant Range Correction

Slant range correction (rectilinearization) corrects for changes in aspect ratio from nadir to the edge of the scan. Ground distances measured on the image from nadir to ±50° must be linear to within 2 percent. The average density caused by slant range correction must not vary more than 1 gray scale across the image perpendicular to the line of flight.

Permanent Record

The method used to record data can improve the fire surveillance system's operation or preclude its use. Fire surveillance requires a photographic-quality image processed in the aircraft within minutes after the plane has passed over a given area. The type of photographic material used to record the image can also enhance or limit the equipment's capability. Material (and equipment to print the material) must be carefully selected.

Spectral band B signals are used to make a printed image at least 8 inches wide. The hot target marker, derived from the spectral and time correlation of the signals from spectral bands A and B, is inserted into the printing video to mark all fire targets on the imagery for easier identification. A fiducial mark in the margin of the image is alined with the hot target marker for easier target location.

Mileage marks, derived from the navigation system, mark the margin of the imagery to indicate the relative number of miles traveled. Annotation in the margin of the image clearly identifies the mission by number, date, time, and location.

Target Alarm

A fire target alarm maintains a visual indication of a hot target until the operator manually resets it.

Monitors

The FFSE must contain an equipment monitoring oscilloscope to calibrate the spectral discrimination signals, to evaluate signal quality during image flights, and to detect and locate equipment failure in flight and on the ground.

Environment

The FFSE must meet all environmental requirements normally applied to any given installation in an aircraft. For example, temperatures can vary from -40° C. at high altitudes to +55° C. on hot runways. Shock and vibration should be within normal limits for manned aircraft.

AIRCRAFT PERFORMANCE REQUIREMENTS

The performance of the aircraft for infrared fire surveillance determines whether the system is capable of only fire mapping, fire detection, or both. Certain performance requirements, which are listed below, can limit the operation. The lower performance requirements cited are applicable to fire mapping, whereas the higher performance requirements are desirable for fire detection. The minimum requirements needed to accomplish both missions are listed in the normal range column that follows. Doppler or inertial navigation system is required in both cases.

	Lower	*Normal range*	*Higher*
1. Altitude over terrain (feet)	500	2,000/25,000	50,000
2. Range (nautical miles)	1,000	1,200	3,000
3. Speed (knots)	50	85/250	600
4. Equipment weight (less crew, pounds)	[11]600	[11]750	[11]1,000
5. Pilot and aircrew (number)	2	2	3

The complete "Performance Requirements and Technical Specifications for Airborne Infrared Forest Fire Surveillance Equipment" will be prepared at the Northern Forest Fire Laboratory and held for those who need a complete specification of the infrared system.

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[11] Includes auxiliary equipment such as the navigation system, vertical gyro, and power inverter.

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